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FLAMMABILITY OF WIDER CONVEYOR BELTS USING LARGE-SCALE FIRE TESTS

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Abstract

The Mine Improvement and New Emergency Response Act of 2006 (MINER ACT) established a Technical Study Panel (The Panel) to provide recommendations on the utilization of belt air and new technology that may be available for increasing the fire resistance properties of conveyor belt used in underground coal mines. The Panel Report recommended use of the Belt Evaluation Laboratory Test (BELT) as the method for testing and approval of flame resistant conveyor belts used in underground coal mines. The research conducted to establish the correlation of the BELT with large-scale belt fire flammability tests was done using 36- to 42-in wide conveyor belt. Due to today's coal haulage capacity, the mining industry is using 72-in and wider conveyor belts. The National Institute for Occupational Safety and Health (NIOSH) conducted a study to determine if the BELT will also qualify wider belts as fire resistant for use in underground coal mines. This paper describes the results of recent experiments comparing results from using the BELT and the large-scale tests for six different belts.

Introduction

The 2G test, described in 30 CFR 18.65, has been used for acceptance of fire resistant belting since 1955. The accepted method was mandated by the Federal Coal Mine Health and Safety Act of 1969 to qualify a belt as fire resistant for use in underground coal mines in the United States. To conduct the 2G test, a 6-in-long by 0.5-in-wide sample of belt is exposed to a flame from a Bunsen burner in still air for one minute with the transverse axis at 45 degrees inside a 21-in cubical test gallery. After 1 minute, the flame is removed and the sample is exposed to air at a velocity of 300 feet per minute. The belt passes the test if the flame duration is less than one minute for 4 samples of the same belt, or if the afterglow is less than an average of 3 minutes. In their report, the Panel noted that the 2G test has various deficiencies, as seen in the persistence of belt fires in underground coal mines (1).

The U. S. Bureau of Mines (USBM), in cooperation with the Mine Safety Health Administration (MSHA), first addressed the use of the 2G test to evaluate conveyor belt fire resistance in laboratory-scale tests in the early 1980's (2). Large-scale tests were conducted in the mid 1980's to compare the results of the 2G test to results in large-scale conveyor belt fire tests (3). In this study, nine synthetic rubber belts and eight PVC belts were evaluated in full-scale fire tests in the Lake Lynn Fire Gallery. Of the 17 belts tested, 16 were rated as MSHA accepted fire resistant based on the 2G test. One belt was rated as non-fire resistant. Of the 16 belts that passed the 2G test, eleven belts failed the Fire Gallery test criteria, exhibiting flame spread and belt damage beyond the ignition area, while 5 belts passed the test. Based on these results, NIOSH and MSHA worked to develop a new laboratory-scale test apparatus and method for evaluating the fire resistance of conveyor belts that more closely correlated with the results of the large-scale Fire Gallery results (4,5). Further research was completed comparing the apparent fire resistance of 21 conveyor belts based on tests conducted in the Fire Gallery and a new laboratory apparatus (6). Of the 21 belts tested, the results showed that 19 were in full agreement based on the pass/fail criterion developed for the two test methods. Based on the results of the large-scale conveyor belt fire tests and new laboratory-scale test work, MSHA published a proposed rule in 1992 to replace the 2G test with this new laboratory method (BELT) (7). In July 2002, the proposed rule was withdrawn. MSHA cited a significant decline in conveyor belt fires from (1993-2002), belt monitoring improvements such as fire detection, and technology advancement, such as roller and bearing improvements to minimize friction on the belt, as reasons for withdrawing the proposed rule (8).

The Panel Report recommended the immediate implementation of the BELT as the method for testing and approval of flame resistant conveyor belts (1). However, since the correlations between the laboratory-scale tests and the full-scale tests used to establish the BELT method were based on 36- to 42-in wide conveyor belts, NIOSH and MSHA decided to conduct experiments to determine if the correlation is still valid for the wider conveyor belts typically used in mines today. This report describes the results of experiments conducted on a number of wider belts using the laboratory-scale BELT method and large-scale tests in the NIOSH Fire Suppression Facility.

Belts Evaluated

The conveyor belting chosen for this research was purchased as brand new conveyor belting from each manufacturer. Each belt is 72-in wide. The goal in choosing the conveyor belts was to evaluate different types of belts used in the mining industry in the U.S. and other foreign countries today. Three different types of belt material were selected; polyvinyl chloride (PVC), styrene butadiene rubber (SBR), and chloroprene. Three of the belts meet three different US standards, non-fire resistant, 2G accepted, and BELT approved. The three other belts meet foreign fire resistance standards, Australian, British and German. Table 1 shows the type of belt material, standard approval, construction, strength, and cover dimensions.

Table 1. Conveyor Belts Evaluated

Belt	Type	Standard	Ply	Strength, piw[7]	Covers
1	N[1]	Australian	3	600	3/16x1/16 in
2	PVC[2]	British	SW[6]	800	2x2 mm
3	SBR[3]	NFR[5] US	4	800	3/8x3/32 in
4	SBR[3]	2G US	3	600	3/16x1/16 in
5	SBR[3]	BELT US	3	600	3/16x1/16 in
6	C[4]	German	3	600	3/16x1/16 in

1 Neoprene®
2 Polyvinyl Chloride
3 Styrene Butadiene Rubber
4 Chloroprene
5 Non Fire Resistant
6 Solid Woven
7 Pounds per inch of belt width (widely used in the US)

Experimental Description

Large-scale test

The large scale fire tests were conducted at the NIOSH Fire Suppression Facility (FSF). The FSF, shown in Figure 1, is a full scale, state-of-the-art fire test facility located on the surface at the Lake Lynn Laboratory in Fairchance, Pennsylvania. The fire tunnel is configured in a tee-shape to simulate a main mine entry and crosscut. The main entry is 153-ft-long and the crosscut is 40-ft-long. For these experiments, the cross-cut was closed off. The entry is 18-ft-wide by 7-ft-high. The FSF is equipped with a 6-ft diameter, variable speed axial vane fan, located at one end of the main tunnel to provide ventilation. The fan has a pneumatic controller to adjust the fan pitch in order to increase or decrease the air velocity.

Figure 1. Fire Suppression Facility

The FSF is equipped with a 9-point gas monitoring array at the open end of the tunnel to measure the gas components produced from a belt burn test. The array is made of ½-in diameter black steel pipe positioned at the center of the entry. A total of nine 1/8-in holes are drilled into the vertical section of the pipe to sample the gases. The sample holes are equally spaced vertically from the roof to the floor. A ½ -in tube is connected to the steel pipe and led back to the control room to a set of infrared gas analyzers. The gas analyzers measure carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) gas concentrations. The gas data was collected every 2 seconds and was recorded by a computer based data acquisition system.

A 9-point thermocouple array is also located at the open end of the tunnel to measure the average exit gas temperature for use in heat release rate calculations. The thermocouples are attached to three vertical ½-diameter steel pipes spaced evenly across the width height of the entry. The heat release rate for each test is computed using the exit gas temperature by the following equation:

$$Q_{total} = Cp \times \rho o \times Ve \times Ao \times \Delta T$$

Where, Cp = heat capacity of air, 1.088 x 10 -3 kJ/g °C
ρo = density of air, 1200 g/m^3,
Ve =average exit air velocity, m/s,
Ao = entry cross section area, m^2, and
ΔT = average exit temperature– initial temperature, °C.

The FSF was equipped with two video cameras to record each test burn. The first camera is mounted in the center of the roof roughly 60 ft from the fan to give a frontal view of the conveyor belt structure during the test. The second video camera is placed on the left side of the tunnel, facing the open end of the tunnel, upstream from the conveyor belt structure, to view the underside of the conveyor belt at the point of ignition. The conveyor belt structure is located 85 ft from the fan and is slightly off center of the entry to allow for heavy equipment to pass on one side to place the belting onto the structure. The conveyor belt structure is 50-ft long and 7.25-ft wide. The trough idlers are 5-in in diameter and are placed at 5 ft intervals.

To ignite the belt, four sets of natural gas impinged jet burners, connected in series, are placed in front of the belt structure as shown in Figure 2. Each burner is equipped with 60 stainless steel jets having a combined rated output of 44 to 114 kilowatts per burner. The ignition region was confined by metal shields on the front, left, and right sides, and the top to form a box around the ignition zone to reduce the effects of the ventilation on the ignition process, shown in Figure 3. The back side was unshielded towards the open end of the fire tunnel.

Figure 2. Gas Burners

Figure 3. Shield for Gas Burners

To conduct a test in the FSF, a 36-ft-long piece of conveyer belt is installed on the conveyor belt structure. The upstream end of the belt is affixed to the burners by metal wire, as shown in Figure 2. Thermocouples are installed on the center line of the belt at 5-ft intervals and along the two edges of the belt at 10-ft intervals, as shown in Figure 4. The first row of thermocouples are placed 2-ft from the front of the belt in the ignition zone. Each thermocouple is placed just below the surface of the belt to measure the belt temperature to determine when the flame reaches that distance on the belt.

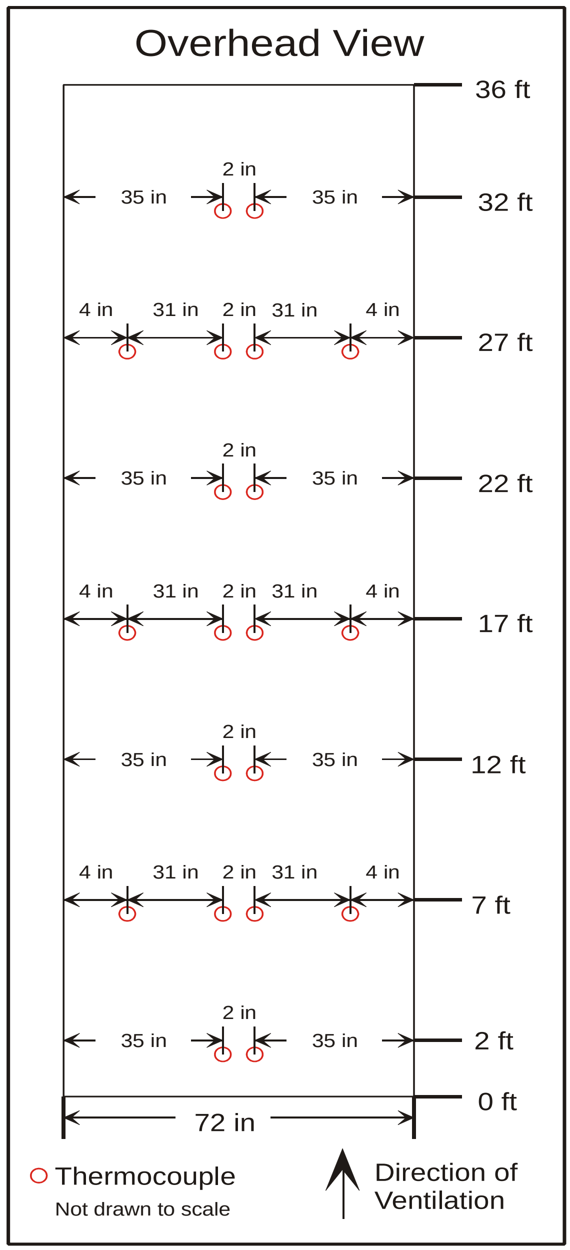

Figure 4. Thermocouple Lay-Out

The air velocity is defined as the airflow over the top center of the belt 17-ft beyond the ignition zone, 1 ft above the surface of the belt. The velocity measurement is made using a hand-held vane anemometer. The pitch of the fan blade is varied to achieve the desire air velocity. Air velocity measurements are also made at the thermocouple and gas points at the exit of the tunnel, 150 ft from the fan. The exit air velocities at each point are averaged together and recorded as the exit air velocity. It is important to mention that once the air velocity was set for the test, at no time was the fan turned off or adjusted until the test was completed.

To ignite the belt, the four sets of natural gas burners are placed 4.5-ft in front of the structure, the belt is secured over the gas burners with metal wire, and the gas burners are ignited with a propane torch. The natural gas is allowed to flow for 10 minutes before it is turned off. The belt is allowed to burn until it is just smoldering with no visible flame or until the entire length of the belt is consumed by the fire. The belt passes the large-scale test if in two separate trials there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if during any of the two trials the belt burns completely to the end.

BELT apparatus

The USBM, in cooperation with MSHA, developed a laboratory-scale flame test known as the BELT test to address the deficiencies of the 2G test. The BELT test can be conducted in a relatively simple laboratory setting that does not require a full-scale fire gallery. The BELT apparatus is a 5.5-foot-long by 1.5-foot-square, 1-in-thick ventilated tunnel made of refractory material. Round stainless steel ducting is used to exhaust the fumes produced from the burning of the belt. A steel rack made of slotted angle iron is used to hold down the belt during the test as shown in Figure 5. To ignite the belt, an impinged jet methane gas burner containing 2 rows of 6 jets is used.

Figure 5. BELT Test Apparatus

To conduct a BELT test, a belt sample is cut to the size of 5-ft long by 9-in wide. The belt is fastened to the angle iron rack with cover side up using cotter pins and washers to prevent it from shrinking away from the burner. The front of the rack is then placed and centered 6-in inside the tunnel. The ventilation for the tunnel is set at 200 feet per minute using a vane anemometer to measure the air flow. The belt is ignited by applying the methane burner to the front edge of the belt with the flames distributed over the top and bottom evenly. The flow of methane to the burner is set at 9.24 cfm. The methane burner is removed after 5 minutes and the belt is allowed to burn until the flames are out. The belt passes the test if in three separate trials there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if during any of the three trials the belt burns completely to the end of the sample.

Results and Discussion

Large-scale test

Initially, tests were conducted using the 2G accepted SBR belt at air flows of 200, 400, 500, and 600 ft per minute to determine the worse case air velocity. This belt was chosen because it is commonly used in the U.S. coal mining industry. To calculate the flame spread rate, the time and distance were recorded when the fire reached each row of thermocouples. The points were then plotted on a graph and the data was fitted by linear regression. The slope of the line is the flame spread rate. The results are shown in the Figure 6 and table 2. The results indicate that the worse case air flow is 400 ft per minute. The plots in Figure 6 show that the flame spread rate is linear over the 36-ft-length for each of the air velocities.

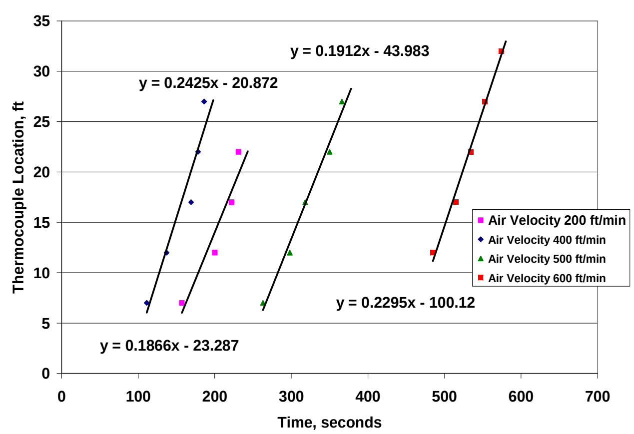

Figure 6. Plot of Flame Spread Rates of 2G Accepted SBR Belting

Table 2. Flame Spread Rates

SBR 2G Belting				
Ventilation Rate (ft/minute)	200	400	500	600
Flame Spread Rate (ft/minute)	11.2	14.6	11.5	13.8

Table 1. Large-Scale Test Results

	Type	Standard	Flame Spread Rate ft/minute	Peak Fire Size Megawatt	Belt Damage ft	Pass/Fail
Belt 1 T1	Neoprene®	Australian	NA	0.22	2.5	P
Belt 1 T2	Neoprene®	Australian	NA	0.30	6	P
Belt 2 T1	PVC	British	NA	0.15	less 1	P
Belt 2 T2	PVC	British	NA	0.13	less 1	P
Belt 3 T1	SBR	non-fire resistant US	flashover	10.00	36	F
Belt 3 T2	SBR	non-fire resistant US	flashover	11.00	36	F
Belt 4 T1	SBR	2G US	14.6	6.00	36	F
Belt 4 T2	SBR	2G US	21.0	9.00	36	F
Belt 5 T1	SBR	BELT US	NA	0.12	1	P
Belt 5 T2	SBR	BELT US	NA	0.09	less 1	P
Belt 6 T1	Chloroprene	German	NA	0.14	2	P
Belt 6 T2	Chloroprene	German	NA	0.13	2	P

After determining the worse case air flow of 400 ft per minute, this ventilation rate was used to evaluate all six belts in the large-scale test. Two tests were conducted for each belt. As mentioned earlier, the pass/fail criterion is based on the damage to the belt. A belt passes the large-scale test if, in two separate trials, there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if during any of the two trials, the belt burns completely to the end. The flame spread rate was calculated for the belts that burned out of the ignition zone. The peak fire size is the optimum heat release rate after the gas burners are turned off. The damage to the belt was recorded as the length of belt burned away from the gas burners. The flame spread rate, peak fire size, amount of belt damage, and pass/fail results are shown in table 3.

The Neoprene ®, PVC, chloroprene, and BELT approved SBR belts (belts 1, 2, 5, and 6) passed the large-scale test based on the stated criteria. These belts did not burn out of the ignition zone and were unable to reach steady-state flame propagation. The peak fire size for these belts ranged from 0.09 and 0.12 megawatts (MW) for the SBR belt to 0.22 and 0.30 MW for the Neoprene ® belt. The small fire size was due to the small amount of belt burned in each test. The worst belt damage was observed for the Neoprene ® belt that meets the Australian standard, which burned 2.5 and 6-ft in the two tests, while the SBR and chloroprene belts burned 2-ft or less.

The non-fire resistant and 2G accepted SBR belts (belts 3 and 4) failed the large-scale test. The non-fire resistant belt flashed over setting the entire belt on fire at once, causing damage to the thermocouples, so no flame spread rate could be obtained. The non-fire resistant belt burned completely to the end of the sample. The 2G accepted SBR belt flame spread rate was 14.6 for the first test and 21.0 ft per minute the second test. The peak fire size for the non-fire resistant belts was 10.0 and 11.0 MW, while the peak fire size for the 2G accepted SBR belts was 6.00 and 9.00 MW.

BELT results

The results of the BELT tests are shown in table 4. In this test, the Neoprene ®, BELT approved SBR, and chloroprene belts met the pass criteria. The PVC, non-fire resistant SBR, and 2G accepted SBR belts failed.

Table 4. BELT Test Results

	Type	Standard	Pass/Fail
Belt 1	Neoprene®	Australian	P
Belt 2	PVC	British	F
Belt 3	SBR	non-fire resistant US	F
Belt 4	SBR	2G US	F
Belt 5	SBR	BELT US	P
Belt 6	Chloroprene	German	P

Summary

Six different types of 72-in-wide conveyor belting that were deemed acceptable by different flammability standards were evaluated for fire resistance under large-scale test conditions. Full-scale fire experiments were conducted in the NIOSH Fire Suppression Facility and the results were compared to the results of laboratory-scale BELT. Of the six belts tested in the large-scale tests in the FSF and the BELT apparatus, five of the belts produced similar results. The Neoprene ®, BELT approved SBR, and chloroprene belts passed both tests. The non-fire resistant and the 2G accepted SBR, as expected, failed in both tests. The PVC belt that meets the British standard passed the large-scale test, but failed the BELT test. In the case where the large-scale test results did not correlate for the one PVC belt, the BELT test provided a more conservative result. Although the test difference is not completely understood for the one PVC belt, a partial explanation may be related to lower concentration of the combustible atmosphere generated in the full scale test and greater heat loss versus the BELT during the combustion process of the PVC belt. Overall, these experimental results indicate the BELT represents a reasonable correlation of the fire resistance characteristics of wide conveyor belting under full scale fire conditions as tested in the FSF. Also, the experimental tests of the 72-in-wide belts in the FSF were comparable to the previous large-scale test results of the 36-42 in-wide conveyor belts conducted by the USBM. As the industry moves to even wider and thicker belts in the future, there will continue to be a need for large-scale experimental studies to ensure that the correlation between the BELT method and conveyor belt fire resistance is maintained.

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